Chapter 3
Effect of Bottom Flange Angle Blocking on the Dynamic Response of Two All-Steel Laboratory Floors

Sahabeddin Rifai, Rajshri Chidambaram Muthu Kumar, Feras Abla, Ahmad Rababah, Onur Avci, Matthew R. Eatherton, and Benjamin W. Schafer

Abstract This paper presents an experimental investigation into the effect of angle blocking on the dynamic behavior of all-steel laboratory floors. Two all-steel floor specimens, one unbraced and the other braced with angle blocking members, were subjected to dynamic testing to evaluate the impact of this design modification on the floor's dynamic behavior. The results demonstrate that angle blocking significantly enhances the dynamic behavior of the specimens, increasing both modal frequencies and stiffness. The findings indicate that angle blocking installation is an effective method for controlling beam torsion and increasing stiffness, thus improving vibration serviceability. The study's findings have significant implications for the design and construction of steel floors in modern buildings, particularly in office spaces where floor vibration complaints are prevalent.

Keywords Angle blocking · Dynamic testing · All-steel floor · Modal testing · Modular construction

Introduction

All-steel floor systems are distinguished by their low self-weight and limited inherent damping, which can make satisfying vibration serviceability criteria particularly challenging. This challenge is compounded by the need for longer beam and girder spans in modern building design [1]. In addition, the trend towards more open and flexible office layouts, featuring reduced partitioning and lighter furniture, has contributed to a growing concern about floor vibration serviceability in modern office buildings [2].

Furthermore, long unbraced steel beams supporting the floors are prone to torsional and sideways movement, which can be particularly problematic in terms of dynamic behavior and vibration serviceability when the diaphragm on top of the beams is slender. Connecting the bottom flanges of the W-beams, using angle blocking members provides lateral bracing to the floor and it is a promising solution to address these challenges. Angle blocking can help to reduce the torsional movement of beams and increase the stiffness of the floor, thereby improving its overall dynamic behavior. By providing additional lateral support to the floor, angle blocking can help to mitigate the effects of bottom flange sway and reduce the potential of floor vibration complaints. In addition, angle blocking can be easily applied to existing floor systems, making it a practical and cost-effective retrofit option for improving floor vibration serviceability.

The FastFloor system examined in this study eliminates the need for concrete on steel deck components, which are predominantly used in traditional composite floors [3]. FastFloor is a pioneering, modular steel floor system designed to meet the goals of the "Need for Speed" initiative by American Institute of Steel Construction (AISC). The FastFloor system aims to reduce steel construction time by up to 50%. By prefabricating modular units off-site and minimizing non-steel

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components, FastFloor facilitates rapid construction and erection on steel girders, featuring a reduced weight and carbon footprint [1]. A typical full-bay FastFloor is designed to be 30 ft × 40 ft on plan. However, the tested specimen configurations are 10 ft × 40 ft slices (modules) of the full-bay FastFloor.

This study aims to investigate the dynamic behavior of a scaled-down FastFloor specimen in a controlled laboratory environment through experimental modal testing on two FastFloor modules with unbraced and braced conditions. The bracing is achieved by welding angle blocking members to the bottom flanges of the beams with the goal of preventing the torsional movement of beams and increasing the stiffness of the floor. The experimental results provide valuable information on the vibration modes and frequencies of the specimens, and the contribution of the angle blocking to torsional beam movement. The findings of this study contribute to the understanding of the effectiveness of angle blocking installation for improving floor vibration serviceability and provide valuable insights into the design and construction of steel floors in modern buildings.

FastFloor Specimen Configurations

Two FastFloor specimens, each measuring 10 ft in width and 40 ft in length in plan, were prefabricated off-site and shipped to the West Virginia University's Structures Laboratory for vibration testing. Each specimen was tested with and without the angle blocking members to evaluate the effect of bracing on the overall vibration response. Fig. 1-a shows the bare conditions of a typical 10 ft × 40 ft specimen, while Fig. 1-b illustrates the sample specimen braced with angle blocking members welded to the beams' bottom flanges at L/3 and 2L/3 along the specimen length (L).

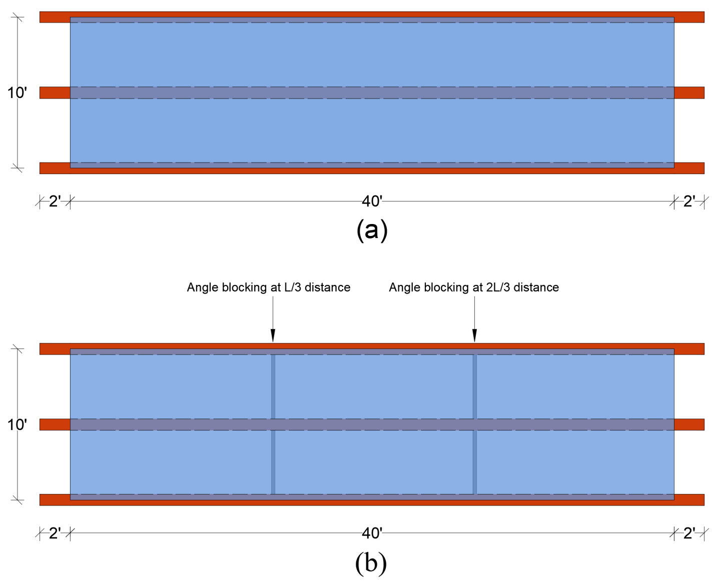

Fig. 1 Layout of a typical 10 ft × 40 ft single FastFloor module tested in this study. (a) Unbraced configuration, showing the beams without bracing. (b) Braced configuration, featuring angle blocking members installed at L/3 and 2L/3 distances on the beam's bottom flanges.

Each specimen represents a single module of the full-bay FastFloor system. The specimen configurations are summarized in Table 1. The testing program consisted of four configurations: SM68_RAF, SM68_RAF_AB_L3, SM94_RAF, and

Table 1 Configurations of the FastFloor specimens.

Specimen	SM68_RAF	SM68_RAF_AB_L3	SM94_RAF	SM94_RAF_AB_L3
Beam Sections	W24×68	W24×68	W24×94	W24×94
Plate Thickness	3/8 in.	3/8 in.	1/2 in.	1/2 in.
RAF	Standard	Standard	Standard	Standard
Angle Blocking	NA	At L/3 and 2L/3	NA	At L/3 and 2L/3

SM94_RAF_AB_L3. These configurations were designed to evaluate the effect of beam size, plate thickness, and bracing conditions on the vibration response of the FastFloor system. Shuriken blind bolts were used to connect the plate to the beam's top flange on one side, while staggered welding was applied on the remaining beam-plate connections.

The pin-supported beams are spaced 5 ft apart, and the main span of the specimens is 40 ft. The raised access floor (RAF) panels are supported by 125 adjustable steel pedestals per specimen, each panel measuring 2 ft $\times$ 2 ft in plan. To limit the torsional behavior of the beams, L3$\times$3$\times$1/4 profiles are welded to the bottom flanges at L/3 and 2L/3, as shown in Figs. 1 and 2. Specifically, Fig. 2-a illustrates a section of the lighter specimen (SM68_RAF_AB_L3) with angle blocking, while Fig. 2-b shows a section of the heavier specimen (SM94_RAF_AB_L3) with angle blocking. For all dynamic tests discussed in this paper, RAF units were in place.

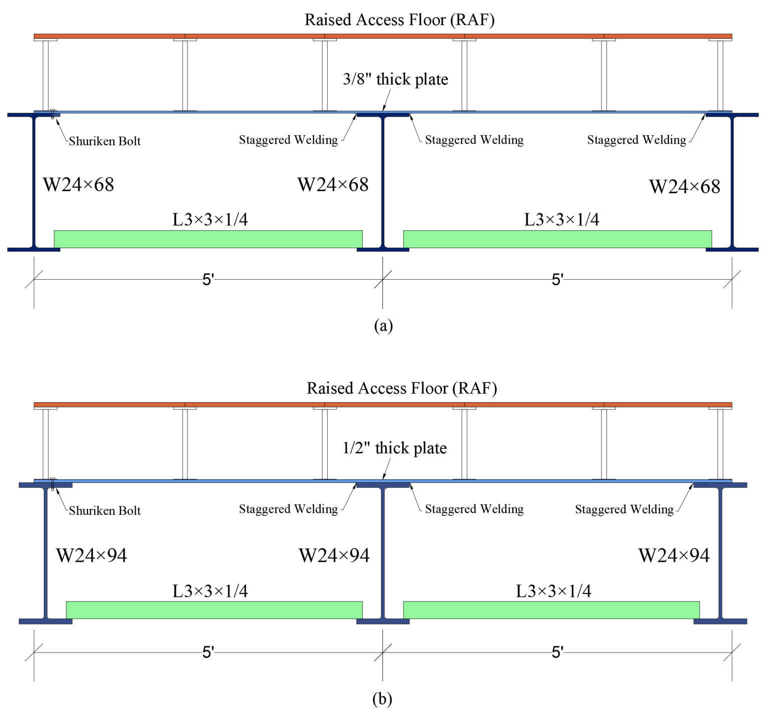

Fig. 2 Sectional view of the braced 10 ft $\times$ 40 ft FastFloor modules tested in the project. (a) Section of the lighter specimen (SM68_RAF) with angle blocking. (b) Section of the heavier specimen (SM94_RAF) with angle blocking.

Modal Testing of the FastFloor Configurations

Experimental modal testing was performed on the four configurations listed in Table 1 to determine the dynamic characteristics of the specimens. Acceleration response data in the gravity direction were collected from 99 points on each specimen. Accelerometers were placed on the top of the RAF panels to obtain accurate dynamic properties and high-resolution mode shapes. The points were spaced at 15-inch intervals in the short direction and 48-inch intervals in the long direction. The denser spacing in the short direction was intended to capture the critical deflection direction for most of the vibration modes. The vertical input excitations generated by a dynamic shaker were measured by an accelerometer located at point 19 (Fig. 3), which was positioned near the shaker. The input is represented by low-amplitude excitations (less than 5%g) at the shaker location.

The collected acceleration data were postprocessed using MEScope [4] to obtain the frequency response functions (FRFs) and mode shapes. For each test configuration, 99 FRFs were calculated using the input from the low-amplitude dynamic mass shaker excitations, with accelerations recorded at point 19 remaining below 5%g [3]. Fig. 4 presents the 99 merged FRFs from testing the unbraced light specimen (SM68_RAF), showing the natural vibration frequencies and damping ratios annotated. Subsequent testing was conducted after the installation of angle blocking members at L/3 and 2L/3 locations throughout the length to form SM68_RAF_AB_L3, and the resulting FRFs are shown in Fig. 5. The mode shapes of the first eight global vibration modes are illustrated in Fig. 6 and Fig. 7 for the unbraced and braced light specimens, respectively.

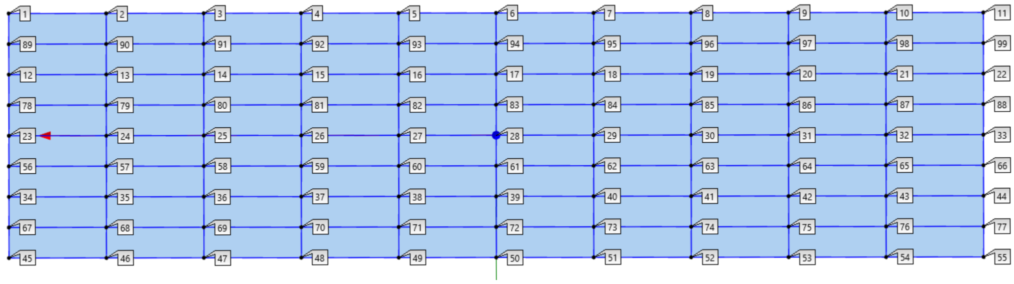

Fig. 3 The floor plan indicating the 99 points used for accelerometer positions. The dynamic mass shaker was located at point 19 for all dynamic excitations.

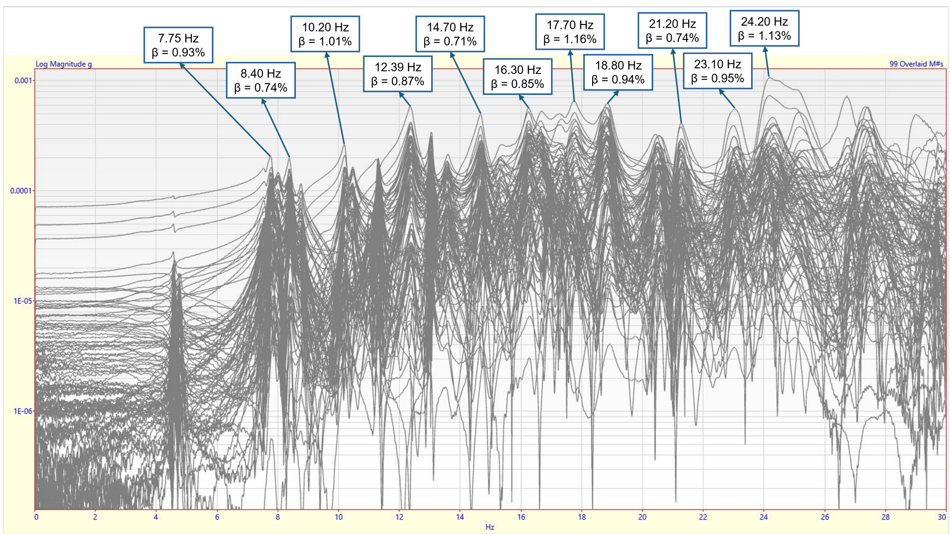

Fig. 4 Frequency response functions (FRFs), natural frequencies and damping ratios of major vibration modes of the light specimen with bare conditions (SM68_RAF), obtained using low-amplitude dynamic shaker excitations.

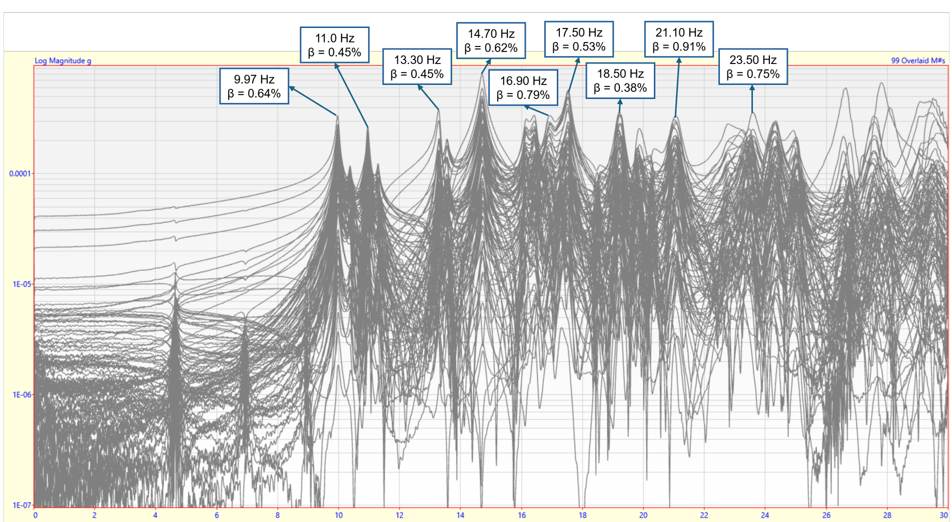

Fig. 5 Frequency response functions (FRFs), natural frequencies and damping ratios of major vibration modes of the light specimen with angle blocking (SM68_RAF_AB_L3), obtained using low-amplitude dynamic shaker excitations.

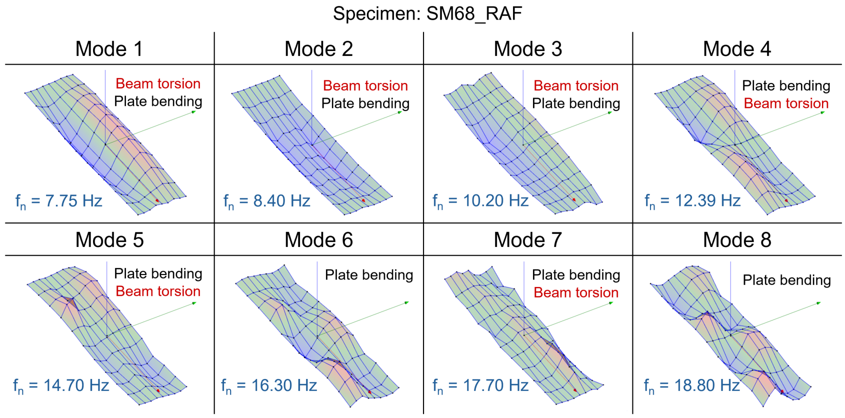

Fig. 6 Mode shapes and natural frequencies of the first eight global modes, obtained from experimental modal testing on the unbraced SM68_RAF specimen.

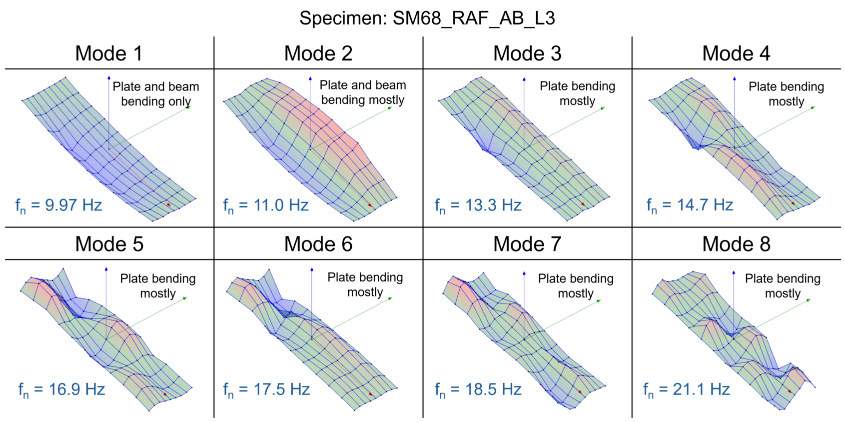

Fig. 7 Mode shapes and natural frequencies of the first eight global modes, obtained from experimental modal testing on the SM68_RAF_AB_L3 specimen with angle blocking.

A comparison of the natural frequencies, mode shapes, and torsional behavior in the modes of SM68_RAF and SM68_RAF_AB_L3 demonstrates the effectiveness of angle blocking in controlling the beam torsion and increasing the stiffness and frequencies of the specimen. The frequency content shifts to the right on the FRF plot, indicating increased stiffness as a result of the angle blocking installation. Specifically, the addition of angle blocking increases the first natural frequency from below 9 Hz to above 9 Hz, thereby rendering the braced specimen a high-frequency floor (HFF) and altering its response to human-induced dynamic loads per design guidance [2]. Furthermore, the second mode of SM68_RAF, which involves plate bending and beam torsion, is eliminated after the addition of the angle blocking. Although the torsional movement of beams is not visible in the mode shapes due to the test setup, separate modal testing was conducted with accelerometers placed perpendicular to the beam webs (perpendicular to the gravity direction) to identify the torsional behavior. Additionally, mode shapes from calibrated finite element models were used to further investigate the torsional behavior of the beams.

The second, heavier specimen exhibits greater stiffness than the lighter one and is classified as a high-frequency floor (HFF), resulting in a less congested frequency content between 0 and 30 Hz. Fig. 8 and Fig. 9 present the merged 99 frequency response functions (FRFs) of the heavy specimen for the unbraced and braced conditions, respectively. Similar to the first specimen, the addition of angle blocking significantly reduces the beam torsion and increases the overall stiffness of the test module. Furthermore, the first mode of SM94_RAF, characterized by beam torsion and plate movement, is nearly eliminated due to the inclusion of angle blocking, as shown in Fig. 10 and Fig. 11. The mode shapes of the first eight global vibration modes are illustrated in Figs. 10 and 11 for the unbraced and braced specimens, respectively.

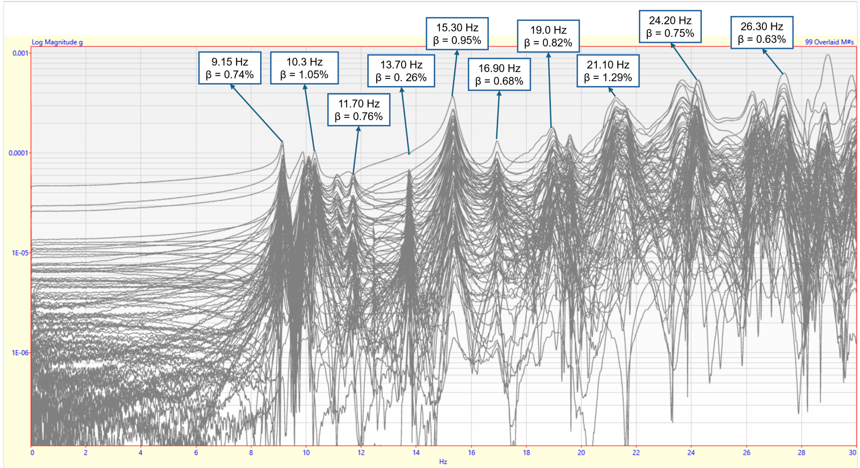

Fig. 8 Frequency response functions (FRFs) with natural frequencies and damping ratios of major vibration modes of the heavy specimen (SM94_RAF), obtained using low-amplitude dynamic shaker excitations.

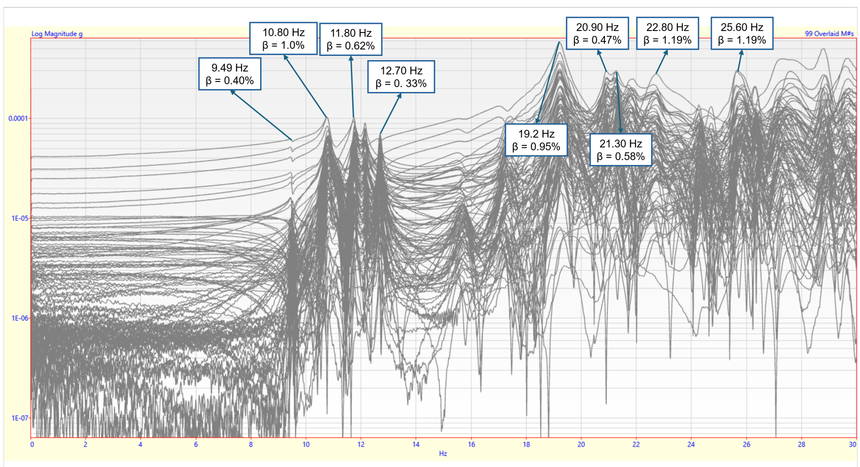

Fig. 9 Frequency response functions (FRFs) with natural frequencies and damping ratios of major vibration modes of the heavy specimen (SM94_RAF_AB_L3), obtained using high-amplitude dynamic shaker excitations.

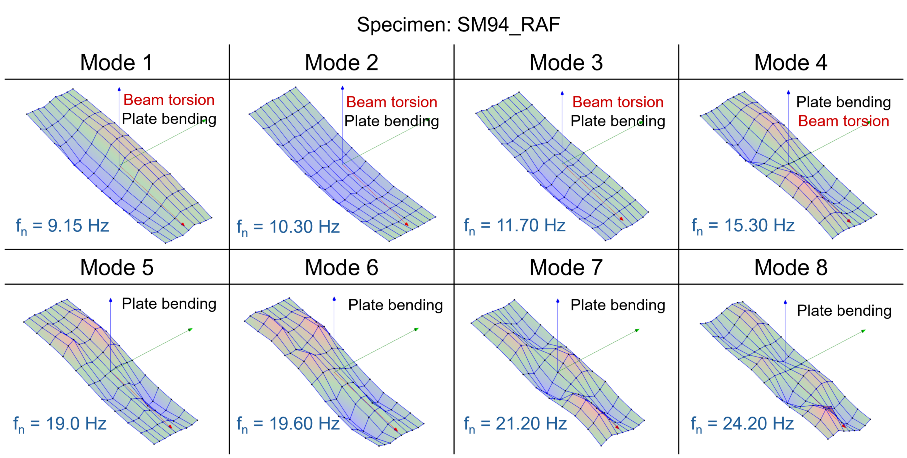

Fig. 10 Mode shapes and natural frequencies of the first eight global modes, obtained from experimental modal testing on the unbraced SM94_RAF specimen.

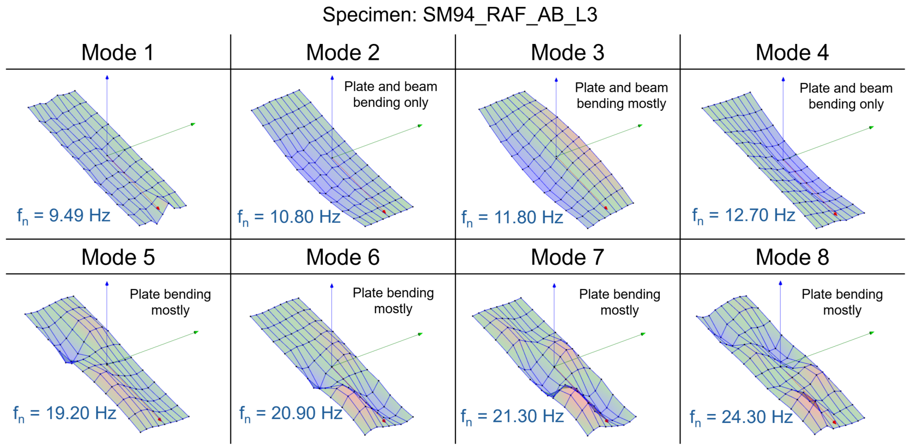

Fig. 11 Mode shapes and natural frequencies of the first eight global modes, obtained from experimental modal testing on the SM94_RAF_AB_L3 specimen with angle blocking.

Conclusions

This study presented a detailed experimental investigation of two all-steel laboratory floor specimens. The effectiveness of the bottom flange angle blocking in improving the dynamic behavior of all-steel laboratory floors was demonstrated. Experimental modal testing and analysis showed that installing angle blocking on the W-beam flanges significantly increases stiffness and limits torsional movement of the beams, thereby enhancing the overall vibration performance of the laboratory floor specimens. These findings contribute to a broader understanding of angle blocking as a practical method for improving the dynamic response of the FastFloor system.

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